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PHYSICO-CHEMICAL HETEROGENEITY OF SUPERFICIAL SOIL LAYERS IN CONIFER PLANTATIONS VERSUS ORIGINAL BROAD LEAF FORESTS IN ARIEGE (PYRENEES, FRANCE)

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ABSTRACT: Changes in physico-chemical properties of superficial soil layers following the substitution of broad leaf trees by conifers have been studied in four Pyrenean sites. Parameter values may change significantly from native to reforested plots, but sometimes in opposite directions. Initial conditions (historical, pedological, and climatic) were not the same in each plot and the present A soil horizon is highly dependent on these. A lessening of organic matter degradation and humification conditions can be, however, inferred from direct humus observations, but differences between physico-chemical properties in native and reforested plots are, nevertheless, quantitatively low, particularly in the pH range usually appropriate for conifer plantations.

INTRODUCTION

The substitution of broad leaf forests by conifers is probably nowadays the most extensive ecosystem manipulation in temperate countries; it may induce severe disturbances in pedogenesis, including frequent humus acidification (Duchaufour and Bonneau, 1961; Nys, 1981; Riha et al., 1986ab; Ranger et al., 1990; Beyer et al., 1991; Weissen and Van Praag, 1991) leading to podzolisation and to a delay in litter decay. The intensity of these changes are under the control of the type of parent material and of the conifer species used in plantations (Bonneau et al.,

1979). Three kinds of reforestation have been studied in this respect: spruce over beech (2 sites), fir over beech (1 site), and pine over oak (1 site). The basic aim of this paper is to bring information about these changes for some important parameters in the superficial soil layers of four Pyrenean sites.

Pedological evolution after reforestation is not limited to physico-chemical changes. Soil parameters may present spatial heterogeneity at a local scale, as observed for pH and organic matter (Riha et al., 1986a; Beniamino et al., 1991). Because they are dependent on tree density among other factors (Riha et al., 1986 ab), these spatial patterns are likely to be affected as well by the plantation process. Our study will address this last point which is not documented in the literature (Nihlgard, 1971) by comparing the spatial physico-chemical heterogeneity of soils in native forests to that in conifer plantations at four study sites.

From our results combined with literature data, we shall attempt to summarize the impact of reforestation on the physico-chemical properties of the superficial layers of soils.

MATERIALS AND METHODS

Study Sites

Four sites in the central Pyrenees (Fig. 1) were selected in the 700-1500 m altitude range: Orgibet (O), Ballongue (B), Col de Rille (R), and Carmil (A). The history and age of the plantations (on grasslands or after clear-cutting) were reconstructed from field inquiries.

Orgibet

The site is located near Orgibet village (Ariege) (42° 56' 28" N, 0° 56' 34" E, altitude o.s.l. 700 m) in the hill zone. Mean annual rainfall is 1,280 mm. The soil developed on colluvium of schistous rocks is brunisol. The native vegetation of the native plot (Oq) consists of a mixed wood of broad leaf species of Pedunculate Oak (*Quercus robur*), Durmast Oak (*Quercus petraea*), birches (*Betula alba*), Common Ash (*Fraxinus excelsior*), and Hazel (*Corylus avellana*). This young forest corresponds to a natural regeneration on a former grassland in fallow for 50 years, but where slight grazing still persists. The reforested plot (Op) established on the same former meadow is covered by Scot Pine (*Pinus sylvestris*), 20 years old, planted at high density (1,800 trees per hectare) with very poor undergrowth. These two sloping plots face south.

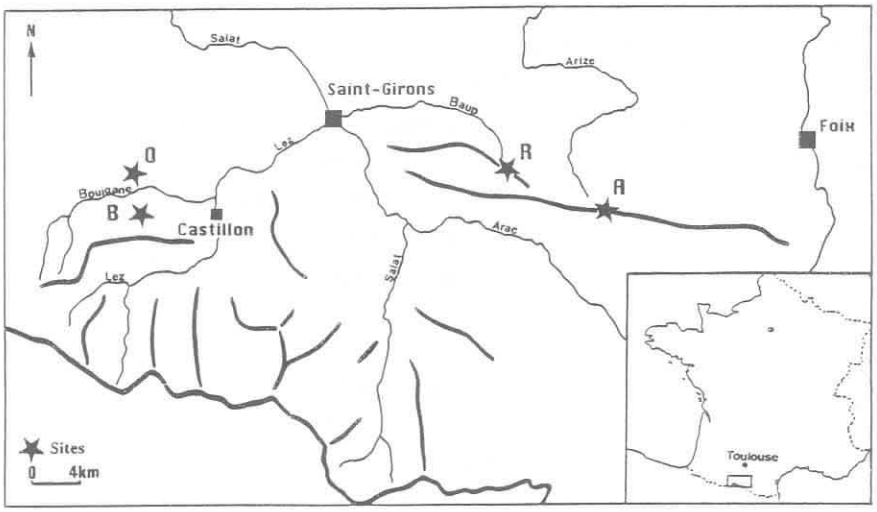

FIGURE 1. Localisation of the study sites: (A) Carmil; (B) Ballongune; (O) Orgibet; and (R) Rille.

Ballongue

This site is located above the Illartein village (Ariege) on a northern slope of the Ballongue forest (42° 54' 44" N, 0° 58' 33" E, altitude o.s.l. 1,080 m). Mean annual rainfall is 927 mm, but summer nebulosity results in a rather constant high hygrometry. Soil is brunisol developed on a very thin colluvium above paleozoic schists. The native plot (Bb) is covered by a monospecific stand of Beech (*Fagus sylvatica*), more than 50 years old, in association with mesohygrophilous-neutrophilous species (Mazars et al., 1991). This area has probably been dominated by Beech for a very long time. It is managed today as a regular timber forest. Conifer reforestation of a large surface of the native forest is planed for the coming years. The plot (Bs) is already planted with Norway Spruce (*Picea abies*), 50 years old, at a high density (1,500 trees per hectare), the undergrowth being as poor as that of Orgibet. Both plots are northern facing slopes.

Rille

The "Col de Rille" is located near the road leading from Rimont to Massat (Ariege) (42° 57' 02" N, 1° 18' 52" E, altitude o.s.l. 920-935 m) Soil is brunisol

developed on a colluvium above paleozoic schists like at Ballongue. Mean annual rainfall is 1,100 mm with high summer nebulosity. The native plot (Rb) is covered by a Beech forest, 30 years old, with some bilberries and ferns in the understorey. It has developed in a former meadow by natural regeneration from nearby forest edges and is at present not exploited. The reforested plot (Rs) is made up of Norway Spruce (*Picea abies*), 25 five years old, planted at a high density (1,250 trees per hectare). Undergrowth is completely lacking, and the soil is covered by dead vegetation. Both plots are northern facing slopes.

Carmil

The Carmil site is located near the road leading from the Peguere pass to the Marrous pass (42° 55' 28" N, 1° 24' 56" E, altitude o.s.l. 1,400-1,450 m). Mean annual rainfall is 1,350 mm with a very high summer nebulosity. Snow persists here for a period of at least two or three months. Soil is brunisol directly developed on schistous parent material. The native plot (Ab) is covered by a Beech forest, more than 50 years old in association with a few native firs. Bilberry (*Vaccinium myrtillus*) and some ferns are present in the understorey. No recent indication of grazing and forest exploitation was noted. The planted plot (Af), covered in the past by the same native forest, is now planted with Grant fir (*Abies grandis*), 20 years old, with a density of 780 trees per hectare. In the undergrowth, bilberry and mosses are present in patches. Both plots are northwest facing slopes.

Physico-Chemical Analysis

Each of the eight plots (four "native" and four "planted") consists of a 8 x 8 m square from which 16 soil samples were collected. In total, 128 soil samples from the A horizon were analysed. The following physico-chemical variables were measured:

Sifting at 2 millimeters (% of large elements) (Gr)

pH in water (pH)

Organic carbon (Anne method) (C)

Total nitrogen (Kjeldahl method) (N)

Exchangeable aluminum (KCI extraction) (Al)

Soil centrifuge moisture (centrifugation 1,000 g) (Eq %)

Bulk density (Bu) from ratio dry weight/volume

Water content on the field (%W), this variable has been measured at the same date in each plot (planted and natural) in one site.

These variables were selected in relation to their biological significance for soil invertebrates which will be analysed in further studies: granulometry, soil centrifuge moisture, and bulk density as markers of soil porosity; pH and exchangeable aluminum (Al) as markers of acidification; and organic carbon/nitrogen (C/N) as markers of nutrient disponibility (Hagvar and Abrahamsen, 1984; Deharveng and Bedos, 1993).

Data Analysis

The software Data Desk was used for statistics and exploratory analysis on a Macintosh Quadra 650.

Conventions and Symbols

The samples made in native tree forests will be referred to as the O samples, those made in the plantation as P-samples.

RESULTS

Humus Forms

Humus forms (Table 1) have been identified in each plot from morphological observation of the O (holorganic) and A horizons, following the Baize and Girard system (1992). The plantation leads in the three plots to the differentiation of a more or less developed OH horizon and to structural modifications of the A horizon expressed by a change in the humus form in comparison with the native plots.

Global Physico-Chemical Analyses of A Layers

The Table 2 gives the mean, standard deviation, and confidence levels (c.l.) of the differences measured in the natural and planted forests, for each variable and for each plot (16 samples). A layers show very different physico-chemical charateritics according to the site. For example, average pH values range from 3.98 in the Carmil planted site to 5.48 in the Orgibet natural site. For average organic carbon, values range from 6.5% in the Orgibet natural site to 15.4% at the Carmil planted site.

Correlations

High order correlations (Table 3) are observed in several cases. The first is pH versus exchangeable Al (-0.937), the second soil centrifuge moisture versus total nitrogen (0.783), soil centrifuge moisture versus bulk density (-0.728), bulk

Table 1. Humus forms

	Orgibet		Ballongue		Rille		Carmil	
HORIZONS	Oak	Pine	Beech	Spruce	Beech	Spruce	Beech	Fir
OL	1-2 cm	1 cm	3-4 cm	1-2 cm	2-3 cm	0.5 cm	2-3 cm	1-2 cm
OF	0.5 cm (sporadic)	0.5 cm	1 cm	1 cm (discontinuous)	0.5 cm (OL or OLv)	1-2 cm	1-2 cm (continuous)	3 cm
OH				1 cm (discontinuous)		in development		1-1.5 cm
A (structure)	Crumb	Crumb	Crumb	A (juxtaposition)	Crumb	LA	Crumb	Microcrumb
Humus forms	Mesomull/ Oligomull	Oligomull	Oligomull/ Dysmull		Mésomull	Dysmull	Dysmull	Amphimull
Trend				>>> Eumoder		>>> Amphimull		>>> Eumoder

Table 2. Mean and standard deviation of variables in each plot. Confidence levels (c.l) of differences for variables measured in natural versus planted forests (Pooledt-test, significant levels: * at p=0.05; ** at p=0.001)

Sites	Gr (%)	pH	C(‰)	N (‰)	C/N	Al ppm	Eq (%)	Bu (x 1000)	W (%)
Orgibet									
Oak									
Mean	13,76	5,48	81,21	4,21	19,76	12,81	46,50	401,13	34,54
S.D.	6,35	0,27	16,20	0,73	4,81	15,41	5,97	49,41	2,95
Pine									
Mean	15,49	5,38	65,26	3,90	17,16	11,75	44,19	475,25	28,39
S.D.	7,32	0,12	11,33	0,76	3,61	6,32	5,19	74,96	3,44
Orgibet c.l	0,4823	0,2081	0,0028 **	0,225	0,1085	0,8003	0,2514	0,0025 **	0,0001 **
Ballongue									
Beech									
Mean	74,66	4,16	78,06	3,77	21,50	225,40	38,69	597,31	25,92
S.D.	6,86	0,07	6,51	0,48	4,36	21,08	1,29	79,53	2,43
Spruce									
Mean	62,23	4,12	68,97	2,85	24,70	256,40	37,94	616,06	18,80
S.D.	8,09	0,12	9,92	0,52	4,10	38,08	4,39	54,62	1,96
Ballongue c.l	0,0039 *	0,4004	0,029 *	0,0019 **	0,0280 *	0,0351 *	0,5579	0,443	0,0001 **
Rille									
Beech									
Mean	16,91	4,34	69,64	4,73	14,91	262,60	52,25	573,66	29,50
S.D.	7,35	0,25	7,57	0,66	2,16	61,00	2,41	62,62	2,98
Spruce									
Mean	2,99	4,24	68,61	4,73	14,78	183,50	57,06	395,81	35,77
S.D.	2,77	0,13	15,55	0,69	3,95	47,20	2,49	52,89	2,71
Rille-c.l	0,001 **	0,1979	0,796	1	0,9552	0,0003 **	0,0001 **	0,0001 **	0,0001 **
Carmil									
Beech									
Mean	19,31	4,07	122,10	7,25	17,29	289,70	60,65	338,54	44,18
S.D.	18,34	0,12	11,75	1,34	3,10	45,18	4,58	78,73	7,06
Fir									
Mean	12,35	3,98	154,40	7,47	21,59	312,60	69,24	254,72	38,52
S.D.	6,58	0,10	40,42	1,40	6,33	46,01	9,50	51,70	6,47
Carmil	0,128	0,0208 *	0,0030 **	0,6778	0,0222 *	0,0888	0,0044 **	0,0013 **	0,0248 *

Table 3. Pearson product moment Correlations

ALL SITES

	Gr	pH	C	N	C/N	Al	E q%	Bu
Gr	1							
pH	-0,265	1						
C	-0,224	-0,368	1					
N	-0,422	-0,342	0,731	1				
C/N	0,386	-0,11	0,323	-0,363	1			
Al	0,195	**-0,937**	0,434	0,431	0,076	1		
E q%	**-0,606**	-0,319	**0,708**	**0,783**	-0,141	0,366	1	
Bu	0,71	0,009	**-0,636**	**-0,693**	0,131	-0,045	**-0,728**	1

ORGIBET

	Gr	pH	C	N	C/N	Al	E q%	Bu	% W
Gr	1								
pH	-0,046	1							
C	-0,191	0,036	1						
N	-0,191	-0,031	0,336	1					
C/N	-0,024	0,034	**0,628**	-0,508	1				
Al	0,084	**-0,749**	0,129	0,147	-0,005	1			
E q%	-0,164	0,11	0,756	0,049	**0,654**	-0,11	1		
Bu	**0,664**	-0,186	-0,343	-0,281	-0,089	0,104	-0,199	1	
% W	-0,5	0,399	0,487	0,323	0,17	-0,185	0,275	**-0,85**	1

BALLONGUE

	Gr	pH	C	N	C/N	Al	E q%	Bu	% W
Gr	1								
pH	0,382	1							
C	-0,174	-0,437	1						
N	-0,013	-0,242	**0,617**	1					
C/N	-0,132	-0,096	0,01	**-0,752**	1				
Al	-0,424	**-0,822**	0,15	0,105	0,014	1			
E q%	-0,021	-0,064	0,295	0,196	-0,006	0,146	1		
Bu	**0,604**	0,297	-0,474	-0,424	0,126	-0,063	-0,033	1	
% W	0,148	0,025	0,378	0,572	-0,392	-0,215	0,081	-0,45	1

RILLE

	Gr	pH	C	N	C/N	Al	E q%	Bu	% W
Gr	1								
pH	0,236	1							
C	-0,023	-0,217	1						
N	-0,01	0,258	0,16	1					
C/N	-0,031	-0,332	**0,724**	-0,552	1				
Al	0,516	-0,417	0,19	-0,138	0,221	1			
E q%	**-0,625**	0,052	-0,082	0,222	-0,211	-0,587	1		
Bu	**0,804**	0,073	0,007	-0,133	0,071	**0,642**	-0,759	1	
% W	**0,764**	0,092	-0,172	0,195	-0,258	**-0,69**	**0,807**	**-0,908**	1

CARMIL

	Gr	pH	C	N	C/N	Al	E q%	Bu	% W
Gr	1								
pH	0,162	1							
C	-0,165	-0,381	1						
N	0,158	-0,534	0,239	1					
C/N	-0,256	0,057	**0,691**	-0,507	1				
Al	-0,009	**-0,676**	0,141	0,47	-0,226	1			
E q%	-0,212	-0,568	**0,601**	0,407	0,251	0,126	1		
Bu	**0,819**	0,487	-0,43	-0,122	-0,268	-0,276	-0,46	1	
% W	**-0,605**	0,131	-0,06	-0,088	-0,004	-0,332	0,028	-0,372	1

density versus granulometry (0.710), and soil centrifuge moisture versus organic carbon (0.708)

Principal Component Analysis

A principal component analysis (Fig. 2) was performed on all samples in order to illustrate the relative incidence of site versus forest type versus sample variability on overall variability. All parameters were considered, except %W which was measured at a different period at each site. Principal component 1 (contribution: 47.5%) is a gradient of organic matter content, positively related to bulk density and negatively related to the carbon and nitrogen content. PC2 (27.8%) ranges from low pH to high pH samples. The four sites are clearly identified in the analysis, the kind of forest (native or planted) being secondarily operative. The Orgibet soils appear the least acid, the Carmil richest in organic matter content, the Ballongue with high bulk densities, and the Rille near the average. Inside each group, samples corresponding to the natural plots are closer to their origin than those of the planted plots. The advanced humus forms (Mesomull...) tend to draw closer to the origin than the raw humus forms (Dysmull, Eumoder...).

The clear between-site differentiation led us to analyse separately the different studied sites with the same set of parameters plus water content (%W).

Site by Site Analyses

Orgibet (Figure 3)

PC1 contribution is 35.5%; the axis opposes bulk density and water content, with correlations of -0.79 and 0.85, respectively. PC2 (22%) has its stronger link with C/N (-0.805), and PC3 (19.8%) to Al (-0.84). In the plan of axes 1 and 2 (Fig. 4), the groups of P-samples and that of O-samples largely overlap, but the majority of P-samples are in the negative part of axis U1, and most oak samples are in the positive part.

Highest values of parameter correlations were found between water content and bulk density, pH water and Al, bulk density and granulometry, centrifuge moisture and C/N, and C/N and C (Table 3).

Confidence levels of differences between original/planted forest are highly significant for organic carbon and water content, which are lower in the P-samples, and for bulk density which is higher in the P-samples (Table 2).

Dispersion indices for the differents factors (Fig. 4) are higher in the planted forest in three cases out of nine. The largest differences are observed for water content and bulk density, which have more scattered values in the plantations, and for Al and pH, clearly more clumped in the plantations.

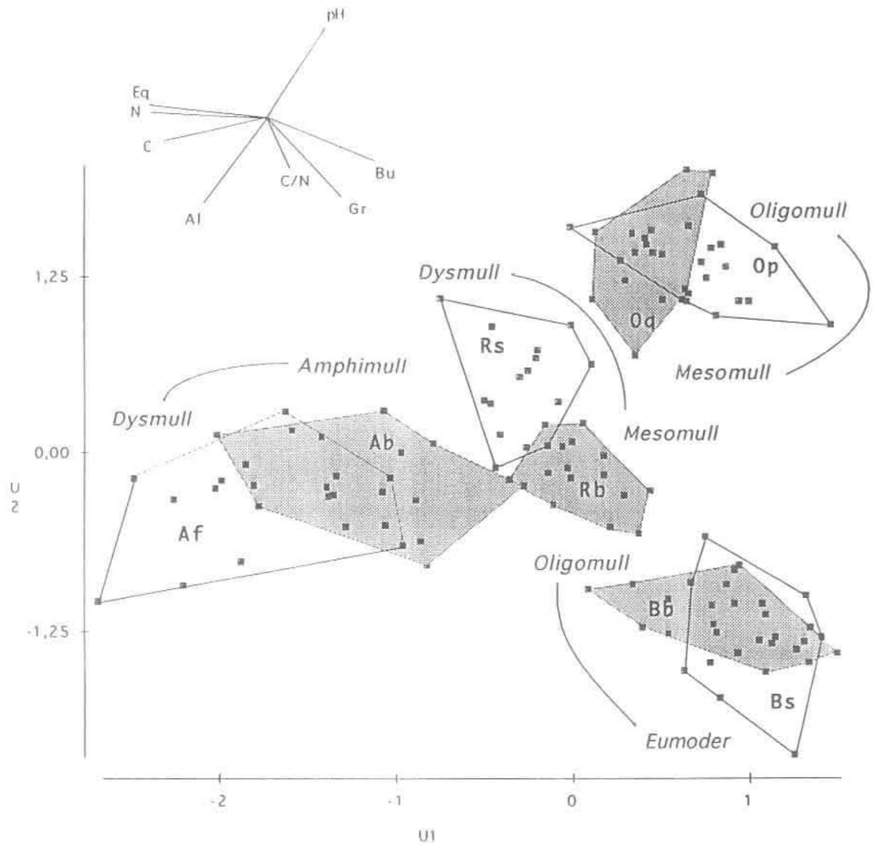

FIGURE 2. Global PCA analysis of the four sites with changes in humus types.

On the whole, the plantation on the slightly acid and Al-poor soil of Orgibet has brought little change in pH, Al, and nitrogen relative to the oak forest natural regeneration, but differences are significant for physical structure (bulk density and water content) and carbon content in the A horizon. Spatial physico-chemical heterogeneity is high in both forest types, with a slightly lower variability under pine.

Ballongue (Figure 5)

PC1 contribution is 33.5%; the axis U1 is correlated to nitrogen (0.81) and carbon (0.76) in its positive part, and bulk density (-0.73) and pH (-0.61) in its

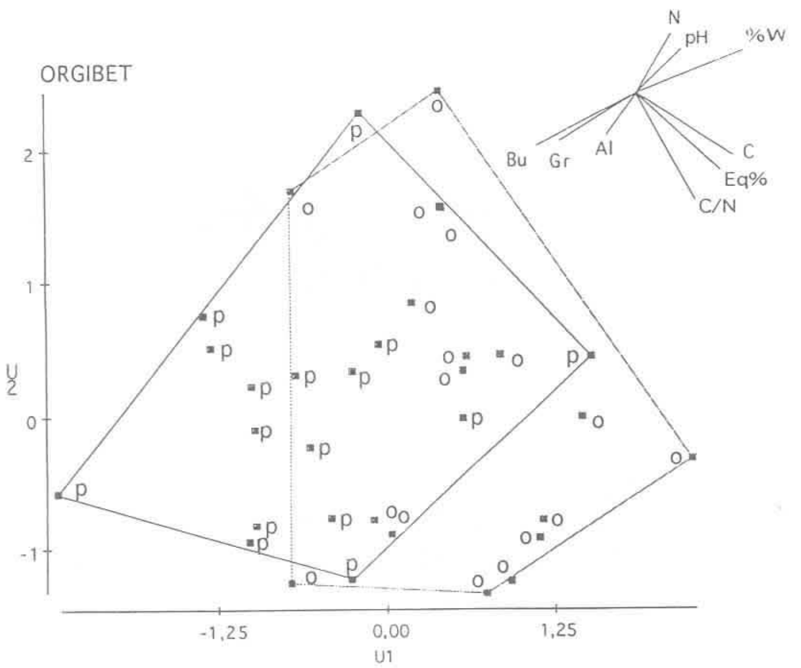

FIGURE 3. PCA analysis of the Orgibet site.

negative part. PC2 (24.7%) is associated to Al (0.71) and C/N (0.61) in positive values and pH (-0.63) in negative ones. PC3 (13.3%) is induced by bulk density (0.61), with low correlation of other factors to this axis. Point cluster overlap is reduced on the plan of axis 1 and 2, with most P-samples in the positive part of axis 2, and the O-samples in the negative part; the overlap is nearly complete on axis 1.

The Pearson product moment showed the highest correlations between pH and Al (-0.822), C/N and nitrogen (-0.752), carbon and nitrogen (0.617), and bulk density and granulometry (0.604) (Table 3).

Confidence levels of differences is high for nitrogen, water content, and to a lesser extent for carbon which is lower in the P-samples. Conversely, C/N and Al were significantly higher in the P-samples (Table 2).

Physico-chemical data were less dispersed in the P-samples, except for soil centrifuge moisture and for water content (Fig. 3).

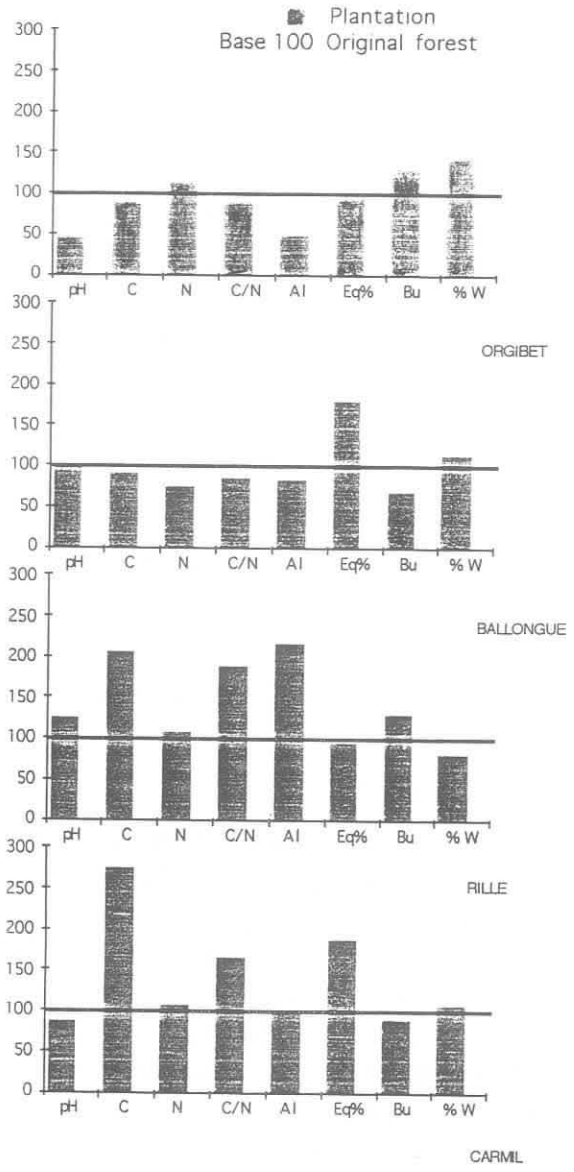

FIGURE 4. Variations in physico-chemical heterogeneity estimated by relative changes in dispersion index (original forest: base 100).

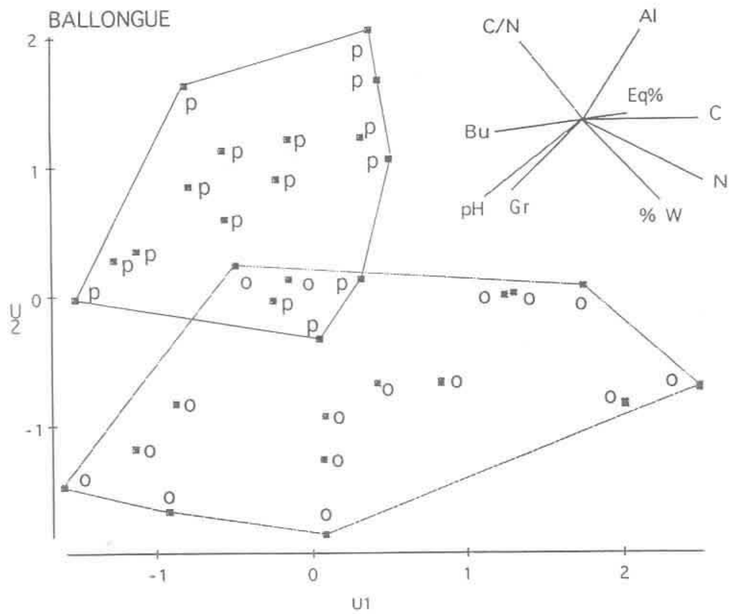

FIGURE 5. PCA analysis of the Ballongue site.

At Ballongue, plantation leads to an augmentation of C/N ratio and exchangeable Al in the A horizon and to a fall of organic carbon. Morphological observation of the A horizon shows an evolution trend from the A horizon of crumb structure, rich in large aggregates and with a fabric composed of droppings, to the A horizon characterized by a loose fabric where organic and mineral particles are separated and by a less decomposed organic matter. This organic matter is lower than that in the native beech forest soil, resulting in the opposition between organic carbon amount and C/N ratio observed in this analysis.This evolution corresponds to the change from oligomull to eumoder with apparition of the thin OH horizon.

Col de Rille (Figure 6)

PC1 contribution is 43.8%; the axis is determined by water content (0.95) and soil centrifuge moisture (0.87) in positive part, and by bulk density (-0.91) and granulometry (- 0.81) in negative part. On PC2 (22.9%), C/N (0.88) and C (0.65) are in positive values and pH (-0.64) in negative ones. PC3 (13.3%) is induced by

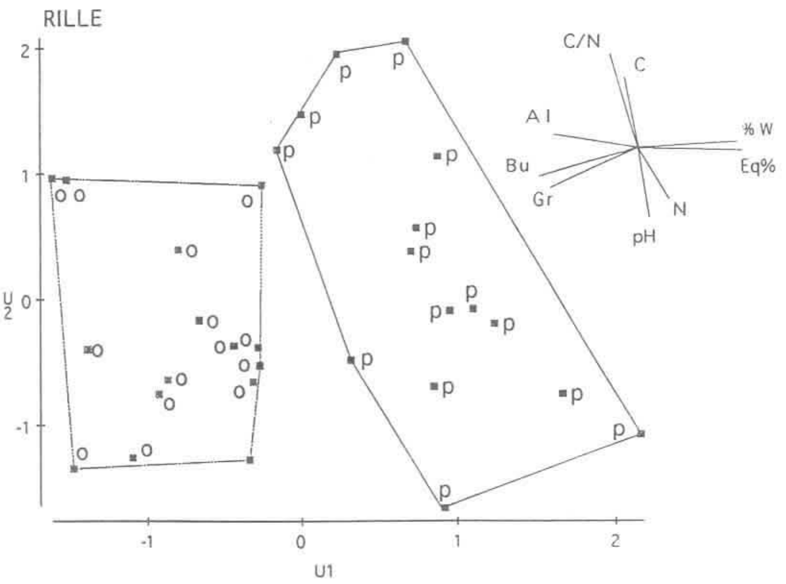

FIGURE 6. PCA analysis of the Rille site

carbon (-0.74) and nitrogen (-0.72). Point clusters do not overlap on axis 1, with majority of the P samples in its positive part.

The Pearson product moment showed highest correlations between bulk density and water content (-0.908), soil centrifuge moisture and water content (0.807), bulk density and granulometry (0.804), granulometry and water content (-0.764), C/N and organic carbon (0.724), and water content and exchangeable Al (-0.690) (Table 3).

Confidence levels of differences are highly significant for Al and for bulk density, which are lower in the P-samples, and for soil centrifuge moisture and water content, which are higher in the P-samples (Table 2).

Data are more dispersed for Al, granulometry, carbon, C/N and to a lesser extent for pH and bulk density in the P-samples. Dispersion is slighly lower for only two parameters (Eq% and %W) (Fig. 3).

The spruce plantation does not show a higher content of Al nor a decrease of pH relative to the oak forest, but rather a decrease of large elements and an increase

of soil centrifuge moisture: LA horizon with high retention capacity begins to develop. The two plots correspond to former meadows developed on a relatively homogeneous soil profile, with a blocky structure and clay texture. Slight differences were observed under spruce which may reflect these former soil conditions rather than merely the effect of the recent plantation. We can explain, in this way, the significant fall of exchangeable Al observed under spruce.

Carmil (Figure 7)

PC1 contribution is 35.8%; the axis is determined by soil centrifuge moisture (0.76) and carbon (0.75) in positive part, and bulk density (-0.82) and pH (-0.78) in negative part. On the axis of PC2 (26.3%), C/N (0.63) and water content (0.61) are in positive values and nitrogen (-0.69), and Al (-0.63) and granulometry (-0.62) in negative ones. PC3 (17.6%) is mainly linked to C/N (-0.68). The majority of the P-samples are in the positive values of axis 1, while the groups are completely overlapping on axis 1.

The Pearson product moment showed the highest correlations between bulk density and granulometry (0.819), C/N and organic carbon (0.691), pH and exchangeable Al (-0.676), and granulometry and water content (0.605) (Table 3).

Confidence levels for six out of the eight parameters are significant, and three are highly significant (Table 2). Among the latter, differences for carbon and soil centrifuge moisture are higher in plantation samples, and bulk density is lower.

Values of carbon, soil centrifuge moisture, and C/N are much more dispersed in the plantation. Differences in heterogeneity are low for all other parameters (Fig. 3).

The plantations induced, therefore, a strong increase of soil centrifuge moisture, C/N and organic carbon, reflecting the evolution from a dysmull to an amphimull and perhaps an eumoder. It results from the accumulation of poorly decomposed organic matter which attacks the underlying mineral fractions. This trend is more clear at Carmil because the soil on this site is the most acid of the four studied soils.

DISCUSSION

(1) On the four sites, humus transformation after plantation illustrates a general trend towards a latent podzolic pedogenesis (Nihlghard, 1971; Bonneau et al., 1979). However, its impact on the A horizon is not clearly reflected by the measured physico-chemical changes, except in the Carmil forest, where the soil is very acid.

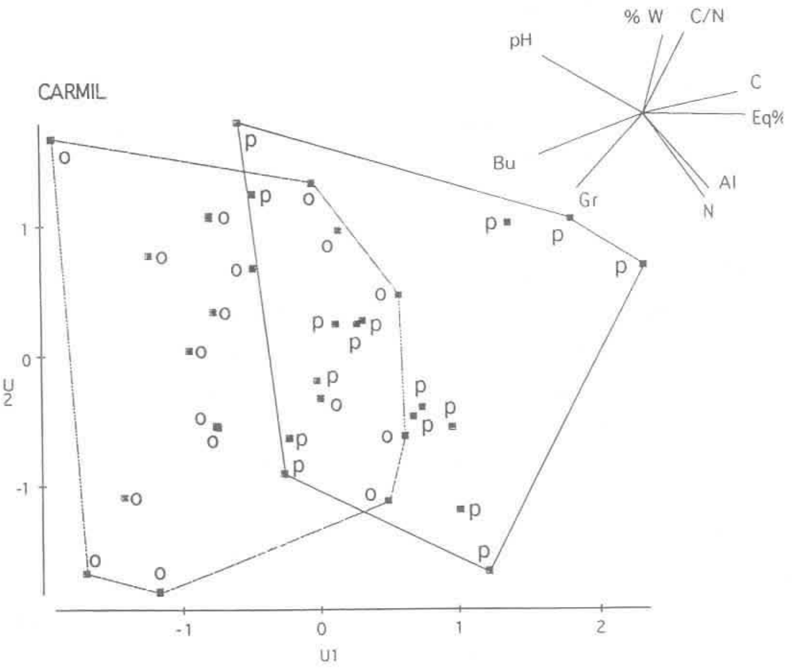

FIGURE 7. PCA analysis of the Carmil site.

(2) Decrease of pH under the conifer plantation, was observed in the four study sites, but the differences are not significant at three of them. Much larger differences (up to 0.5 pH units) are reported by Nihlghard (1971) in similar conditions (40-55-years old spruce plantation over beech, on acid soils). The OH horizon in the plantations of Ballonge, Carmil, and Rille was thicker than in the native forests plots, as was in Nihlgard's study sites in relation to a lower degradation rate. More organic acids are produced as a result, which may account for the decrease of soil pH on the plantations. This explains why similar changes in the OH thickness induce such different changes in pH values between Pyrenees and Norway. The functional links between Al content and pH in acid soils predicts that the later decreases when the former increases. That is roughly confirmed in our data, whereas the reverse was found by Nihlghard (1971) in the superficial layers. Whether local edaphic and

macroclimatic conditions are responsible of these discrepancies will be investigated in future studies.

(3) Changes in other physico-chemical parameters remain low and often not significant between native and reforested plots in the present study (Fig. 2). Moreover, factors change sometimes in opposite directions from native to reforested plots: for instance, bulk density at Rille versus Orgibet. C/N increases from beech to spruce at the Ballongue site, and from beech to fir at the Carmil site, but not from beech to spruce at the Rille site; it decreases from oak to pine at the Orgibet site. Our data, in contrast to the literature (Nihlghard, 1971), do not, therefore, support any general and firm conclusion about the effect of conifer plantations on soil physico-chemistry, not even for a given tree species, such as spruce: intra-site, local conditions may well mask the processes, making it necessary to work on much larger data set, as experimental approach is unrealistic at the scale of times involved.

(4) The relative influence of local site conditions versus effects of tree substitution can be indirectly evaluated by cluster analysis as shown in Figure 8. The study sites are clustered, except for a group of samples from Ballongue which fall to the Rille group. In contrast, the plantation samples and those of original forest are well separated only at Rille, being more or less mixed together at Cazmil, Ballongue, and Orgibet. All of the plantation samples are never grouped. Moreover, it must be emphasized that, whereas the Bellongue and Rille beech forests are rather similar, their spruce plantations are not, indicating that an evolution from close original conditions under the same plantation disturbance do not lead necessarily to the same result in the soil.

(5) This contrasting influence of plantation on soil properties, as evidenced here, may depend on a number of factors, of which a few have been identified so far in the literature: initial pedological conditions (Ranger et al., 1990), nature of the trees (Nihlghard, 1971), soil depths (Bringmark, 1989), distances from the trunk (Beniamino et al., 1991), and tree density (Terlinden and André, 1988). The role of historical conditions, probably important in the often heavily disturbed forests of Western Europe, is particularly difficult to establish. It may explain the contrasting evolution observed at the two sites where beech

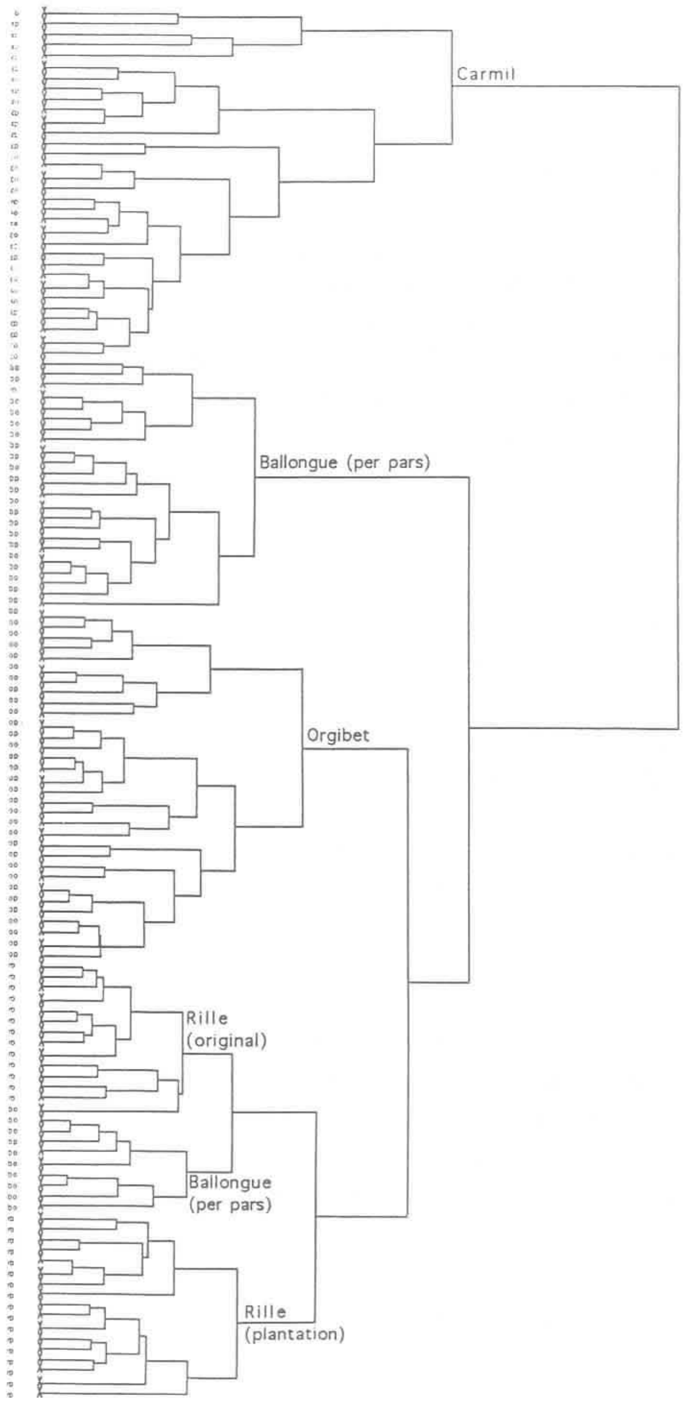

FIGURE 8. Cluster analysis.

has been replaced with spruce (Ballongue and Rille). Organic matter accumulation on the surface soil and decrease of pH generally occur when spruce is planted on former beech forests (Nihlgard, 1971; Ranger et al., 1990): that is the case at Ballongue but not at Rille. In this last site, the native plot and reforested plot have been developed from former meadows, whereas at Ballongue, the site has been dominated by beech for a very long time. Local ecological history has probably a strong incidence on the recent evolution of soils properties in the anciently humanized forests of Europe.

(6) The spatial variability of soil parameters was very different according to the site. At the Orgibet and Ballongue sites, most factors have less dispersed values in the plantation; the opposite was observed at Rille. At Carmil, three parameters are more widely dispersed in the plantation, differences being low for the others. No general trend towards an increase or a decrease of spatial variability in the plantations has been brought to the fore. However, the high heterogeneity of different parameters (for example, carbon and C/N) observed in the planted plots of Rille and Carmil may be linked to the low density of trees in these two plots which lead to a more heterogeneous undergrowth as well as less homogeneous repartition of the throughfall under conifer trees (Aussenac, 1970).

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REFERENCES:

Aussenac, G. 1970. Action du couvert forestier sur la distribution au sol des précipitations. Annales des Sciences Forestières 27(4):383-399.

Baize, D. and M.C. Girard. 1992. Référentiel Pédologique: Principaux sols d'Europe. INRA éds. Paris, France.

Beniamino, F., J.F. Ponge, and P. Arpin. 1991. Soil acidification under the crown of oak trees, I. Spatial distribution. Forest Ecology and Management. 40:221-232.

Beyer, L., H.P. Blume, and U. Irmler. 1991. The humus of a "Parabraunerde" (Orthic Luvisol) under *Fagus silvatica* L. and *Quercus robur* L. and its modifications in 25 years. Annales des Sciences Forestières 48:267-278.

Bonneau, M., A. Brethes, F. Lelong, G. Levy, C. Nys, and B. Souchier. 1979. Effets de boisements résineux purs sur l'évolution de la fertilité du sol. Revue Forestière française 31(3):198-207.

Bringmark, E. 1989. Spatial variation in soil pH of beech forests in relation to buffering properties and soil depths. Oikos 54:165-177.

Deharveng, L. and A. Bedos. 1993. Factors influencing diversity of soil Collembola in a tropical mountain forest (Doi Inthanon, Thailand), pp. 91-111. IN: Paoletti, Foissner and Coleman (eds.) Soil Biota, Nutrient Cycling and Farming Systems Lewis Publishers, Boca Raton, FL.

Duchaufour, Ph. and M. Bonneau. 1961. Evolution d'un sol de forêt feuillue "terra fusca" provoquée par une plantation de Douglas (*Pseudotsuga douglasii*) d'un trentaine d'années. Revue forestière française 13:793-799.

Hagvar, S. and G. Abrahamsen. 1984. Collembola in Norwegian coniferous forest soils, III. Relations to soil chemistry. Pedobiologia 27:331-339.

Mazars, M., J. Dagnac, and Ph. Le Caro. 1991. Les principaux groupements végétaux forestiers des massifs domaniaux de Bellonge sud et de Saint Lary (Ariège). Memires de Biospéologie. 18:105-154.

Nihlgard, B. 1971. Pedological influence of spruce planted on former beech forest soils in Scania, South Sweden. Oikos 22:302-314.

Nys, C. 1981. Modifications des caractéristiques physico-chimiques d'un sol brun acide des Ardennes primaires par la monoculture d'Epicéa commun. Annales des Sciences Forestières 38(2):237-258.

Ranger, J., M. Robert, P. Bonnaud, and C. Nys. 1990. Les minéraux-test, une approche expérimentale in situ de l'altération biologique et du fonctionnement des écosystèmes forestiers. Effets des types de sol et des essences feuillues et résineuses. Annales des Sciences Forestières 47(6):529-550.

Riha, S.J., B.R. James, G.P. Senessac, and E. Pallant. 1986a. Spatial variability of soil pH and organic matter in forest plantations. Soil Sci. Soc. Amer. J. 50: 1347-1352.

Riha, S.J., G.P. Senessac, and E. Pallant. 1986b. Effect of forest vegetation on spatial variability of surface mineral, soil pH, soluble aluminium and carbon. Water, Air, and Soil Pollution 31:929-940

Terlinden, M. and P. André. 1988. Effets de l'intensité d'éclaircie sur les horizons organiques et hémiorganiques du sol en fûtaie équienne de *Picea abies*. Pedobiologia 32:301-309.

Weissen, F.and N.J. van Praag. 1991. Root growth inhibition effects of holorganic moder humus layer under spruce (*Picea abies* K.) and beech (*Fagus sylvatica* L.). Plant and Soil 135:167-174.